Acta Odontologica Scandinavica. 2014; 72: 623–629

informa
healthcare

ORIGINAL ARTICLE

Effect of varying core thicknesses and artificial aging on the color difference of different all-ceramic materials

SIBEL DIKICIER[1], SIMEL AYYILDIZ[2], JULIDE OZEN[2] & CUMHUR SIPAHI[2]

[1]*Department of Prosthodontics, Corlu Military Hospital, Tekirdag, Turkey, and* [2]*Department of Prosthodontics, Gulhane Military Medical Academy, Ankara, Turkey*

Abstract

Objective. Clinicians should reserve all-ceramics with high translucency for clinical applications in which high-level esthetics are required. Furthermore, it is unclear whether a correlation exists between core thickness and color change. The aim of this study was to examine the effects of different core thicknesses and artificial aging on the color stability of three all-ceramic systems. ***Materials and methods.*** Ninety disc-shaped cores with different thicknesses (0.5 mm, 0.8 mm and 1.0 mm) were prepared from three all-ceramic systems, In-Ceram Alumina (IC), IPS e.max Press (EM) and Katana (K). The colors of the samples were measured with a spectrophotometer and the color parameters (L^*, a^*, b^*, ΔE) were calculated according to the CIE $L^*a^*b^*$ (Commission Internationale de L'Eclairage) color system before and after aging. ***Results.*** The effects of aging on color parameters were statistically significant ($p < 0.001$), regardless of core thickness. For all systems, the CIE a^* values increased as the thickness of the core increased. Conversely, such increases in core porcelain thickness were correlated with decreasing CIE L^* and b^* values. Core thickness had a statistically significant effect on color change among the groups. ***Conclusions.*** Different core thicknesses (from 1.0–0.5 mm) and artificial aging affected color stability of the all-ceramic materials tested.

Key Words: *all-ceramic, color, core thickness, aging*

Introduction

Esthetic failure is one of the most common complications of tooth restorations and optimally matching the esthetics of natural teeth with those of artificial teeth is a significant challenge in dentistry. Esthetic, natural and biocompatible all-ceramic restorations have become more popular in the last 10 years [1,2]. The lithium disilicate reinforced IPS e.max Press (Ivoclar Vivadent, Schaan, Liechtenstein) is preferred due to the strength of the improved heat-pressed all-ceramic material, its superior biocompatibility and its good esthetic features. Among CAD/CAM (Computer Aided Design/Computer Aided Manufacturing) systems, Katana (Noritake Dental Co, Nagoya, Japan), composed of yttrium stabilized tetragonal zirconia poli-crystals (Y-TZP) core material and fabricated colored zirconia blocks, is also used due to its good mechanical and esthetic properties. Another all-ceramic system, In-Ceram Alumina (Vita Zahnfabrik, Bad Sackingen, Germany) includes a high-strength aluminum oxide core fabricated using the slip cast technique and was developed for restoring anterior teeth [3].

Clinically, an appropriate color combination is an important aspect of esthetic dental restoration. According to some studies, the esthetic success and optical properties of all-ceramic restorations depend upon several factors, such as surface characteristics [4], core or veneer thickness [5–8], number of firings [9], luting agent [1,10,11] and color shade [12–14]. Most all-ceramic systems require the combination of two layers of ceramic material, such as a 'core' with high opacity and a more translucent 'veneer'. If light passes through the ceramic restoration, the material will appear translucent [6]. Lithium disilicate cores are the most translucent, followed by aluminum oxide cores and Y-TZP cores, respectively [15]. The wide range of colors is related to the core material translucency of all-ceramic systems of clinically relevant core thicknesses. Consequently, the thickness of the core layer determines the definitive shade of an

Correspondence: Dr Sibel Dikicier, Corlu Military Hospital, 59186, Corlu, Tekirdag, Turkey. Fax: +00902826521846. E-mail: dtsibel@hotmail.com

(Received 28 October 2013; accepted 19 December 2013)

ISSN 0001-6357 print/ISSN 1502-3850 online
DOI: 10.3109/00016357.2013.879997

all-ceramic restoration [15,16]. Several studies have attempted to determine the color differences caused by porcelain thickness. Jarad et al. [8] investigated the role of veneering, which affects ceramic thickness, on overall color change. Heffernan et al. [15] reported that translucency was influenced by core and veneer thickness.

When a tooth with intensely discolored dentin requires a ceramic crown, clinicians face a challenge in selecting all-ceramic materials that can be used to achieve a good match. Previous studies have demonstrated that the underlying tooth structure is the primary determinant of the appearance of the definitive ceramic restoration. Such factors as the thickness of the ceramic, the ceramic shade and the cement color should be changed to eliminate this undesirable effect [17–19].

In dental research, The CIE $L^*a^*b^*$system (Commission Internationale de L'Eclairage) is increasingly used to evaluate color changes [3,9,20]. The CIE system defines color in terms of three co-ordinate values (L^*, a^*, b^*) obtained from spectral reflectance measurements taken with a spectrophotometer. The three values provide a numerical description of the color position in a three-dimensional color space. The L^* co-ordinate represents the brightness of an object on the 'Y' axis, the a^* value represents the red or green (positive or negative 'X' axis) chroma and the b^* value represents the yellow or blue (positive or negative 'Z' axis) chroma [5,19]. The color difference (ΔE) between two specimens whose colors are expressed by L^*, a^* and b^* is derived using the following formula:

Several studies have attempted to determine color differences (ΔE) between systems. Seghi et al. [21] investigated the color differences between porcelain systems. Douglas and Brewer [22] studied differences between instrumental color measurement and observer assessment of color differences using metal ceramic crown specimens. ΔE values greater than one unit are visually detectable by 50% of human observers. However, under uncontrolled clinical conditions, such small differences in color are not noticeable, because average color differences below 3.7 are rated as a match in the oral environment.

In the oral environment, all-ceramic materials are prone to aging. Aging can lead all-ceramic materials to change color, to lower bending strength and to reduce anti-fracture toughness. Aging simulates the effects of long-term exposure to environmental conditions through an artificial weathering process that involves light exposure, temperature and humidity [23]. The aim of this study was to determine the color stability of double-layer all-ceramic systems with different core thicknesses which have been subjected to an artificial aging process.

Materials and methods

Three all-ceramic systems were selected for this study. Characteristics of the materials are shown in Table I. In total, nine groups were tested: three different thickness groups for each of the three materials. Disc-shaped, two layered specimens were prepared at core thicknesses of 0.5, 0.8 and 1.0 mm and veneered with 1.0 mm of porcelain. A2 shade veneering porcelain was used on all the ceramic specimens.

Preparation of the specimens

Thirty disc-shaped specimens, 10.0 mm in diameter, were fabricated for each all-ceramic material at thicknesses of 0.5, 0.8 and 1.0 mm. An aluminum mold was also fabricated which consisted of holes with different depths for the preparation of In-Ceram Alumina (IC) discs. An impression was taken from the holes on the mold with vinyl polysiloxane impression material (Reprosil, Dentsply, York, PA, USA) and special investment material (Vita In-Ceram Spezialgips, Bad Sackingen, Germany) was poured into the impression. Consequently, the aluminum mold was duplicated with the investment material. The ceramic powder was mixed with distilled water and condensed in the investing mold. The molds were fired according to the manufacturer's instructions (Vita In-Ceramat 3, Bad Sackingen, Germany) and glass infiltration firing was performed in the furnace at 1100°C for 8 h (Figure 1). Discs were removed from the mold with a diamond burr. The outer glass layer was removed and the airborne-particle abrasion procedure was performed with 35–50 μm of aluminum oxide powder, under a pressure of 2.5 atm, to remove the small glass particles. The final thicknesses of the core discs were verified as 0.5, 0.8 and 1.0 mm (±30 μm) with a digital caliper (Alpha-Tools Digital Caliper, Oakland, NJ, USA). The alumina core discs were cleaned in an ultrasonic cleaner with distilled water.

Table I. Material characteristics for the all-ceramic systems.

Core type	Core thickness (mm)	Code	Brand name	Manufacturer
Glass-infiltrated aluminum oxide core	0.5 0.8 1.0	IC	In-Ceram Alumina	Vita Zahnfabrik, Bad Sackingen, Germany
Lithium-disilicate core	0.5 0.8 1.0	EM	IPS e.max Press	Ivoclar Vivadent, Schaan, Liechtenstein
Yttrium stabilized zirconia core	0.5 0.8 1.0	K	Katana	Noritake Dental Co, Nagoya, Japan

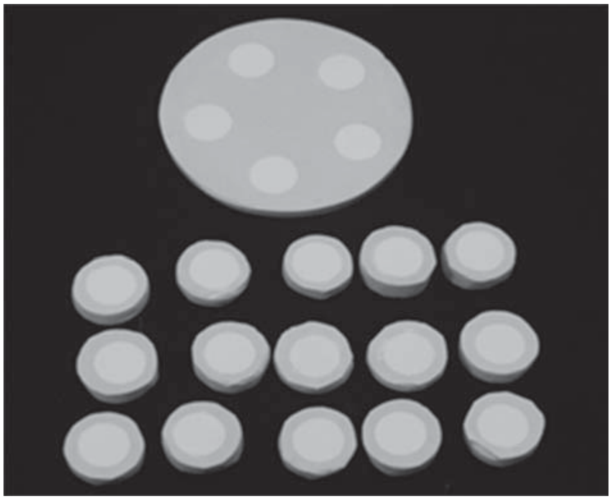

Figure 1. Aluminum oxide core specimens in the investing mold after the firing process.

To prepare the standard 1.0 mm thick veneer porcelain, a silicon index was used for the veneering process. Acrylic pattern discs were prepared at thicknesses of 1.5, 1.8 or 2.0 mm within the metal mold and embedded in silicon impression material (Zetaplus; Zhermack Spa, Badia Polesine, Rovigo, Italy). The acrylic pattern discs were then removed, leaving holes in the silicon material. The alumina core discs were placed into the holes and 1.0 mm thick veneering porcelain (Vita VM 7, Bad Sackingen, Germany) was applied, according to the silicon index, on the disc surface with a brush. Two-layered discs were fired and verified again with a digital caliper. All veneered discs were glazed (Vitachrom L, Vita) at 940°C.

Wax pattern discs for the IPS e.max Press (EM) specimens were fabricated using a stainless steel mold and invested in a phosphate-bonded investment cylinder, according to the manufacturer's instructions. Investment cylinders were heated in a furnace for 1 h at 850°C. IPS e.max Press medium opacity ingots (MO1) were selected for fabricating the ceramic discs. The specimens were heat-pressed (Ivoclar EP 600 Combi, Ivoclar Vivadent, Schaan, Liechtenstein) at 920°C for 25 min. After the investment had cooled, the specimens were divested with airborne particle abrasion using 50 μm glass beads. The residual investment material on the ceramic discs was cleaned by dipping the discs in invex liquid (Invex Liquid, IvoclarVivadent, Schaan, Liechtenstein), which contains less than 1% hydrofluoric acid, for 10 min. The specimens were then left in distilled water for 30 min. The thickness of each specimen was controlled with a digital caliper and reduced until the desired ceramic core thickness was achieved (0.5, 0.8 or 1.0 mm). The veneering process was completed following the IC method: A2 shade veneering porcelain (IPS e.max Ceram, Ivoclar) was applied to the discs and fired in accordance with the manufacturer's recommendations.

Thirty Katana (K) zirconium oxide discs with thicknesses of 0.5, 0.8 or 1.0 mm were fabricated by milling pre-sintered KT13 zirconium blocks (94.4% ZrO_2, 5.4% Y_2O_3) according to the manufacturer's instructions with the Dental Wings CAD/CAM system (DWOS, Montreal, Canada). The zirconium blocks were machined with 1.3 mm in diameter diamond burs in the CAM unit (Yenamak D50, Yenadent, Istanbul, Turkey). All machined discs were designed 21% larger than the desired size to compensate for sintering shrinkage. A digital caliper was used to control the thicknesses. After the milling process, the disc-shaped specimens were sintered at 1400°C for 2 h. A 1.0 mm thick layer of A2 shade feldspathic ceramic (CZR Noritake Dental Co, Nagoya, Japan) was applied to the core discs. A custom-made silicon index was again used to prepare zirconium oxide disc specimens with standard veneer thicknesses.

Color measurements before aging

The colors of all numbered specimens (Figure 2) were measured according to the CIE $L^*a^*b^*$ color scale, using a standard illuminant D65, a standard observer and a white background with a spectrophotometer (Konica Minolta Sensing Inc., CM-2600d, Sakai, Osaka, Japan) before and after the aging process. The spectrophotometer was calibrated with a white ceramic block before each measurement session. The measurements were made from each disc's veneered surface.

Aging process

After the first color measurements of the specimens with the CIE $L^*a^*b^*$ system, the specimens were subjected to the aging procedure consisting of exposure to ultraviolet light and water spray in the weathering machine (Xenotest 150 S+, Atlas Material Testing Technology, Chicago, IL, USA) for 200 h. The veneered surface of each specimen was continuously exposed to the light source. The back panel temperature varied between 70°C (light) and 38°C (dark) and

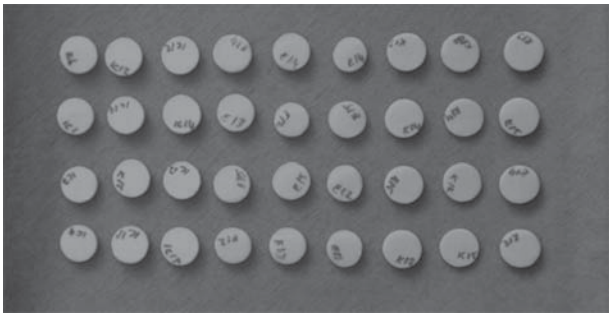

Figure 2. After the veneering process, finished specimens were numbered for the color measurement.

humidity varied between 50% (light) and 95% (dark). The testing cycle consisted of 40 min of light only, 20 min of light with front water spray, 60 min of light only and 60 min of dark with back water spray. The dry bulb temperature was 38°C (dark) and 47°C (light) and the water temperature was 50°C.

Color measurements after aging

After the aging procedures were completed, color analysis was repeated for each of the 90 samples using the same protocol as previously described. The changes in the white-black (L*), red-green (a*) and yellow-blue (b*) color planes were ordered by the Color Mission (Argetek, Istanbul, Turkey) computer software and analyzed. The L*a*b* values for the specimens were measured 3-times and the mean color co-ordinate values were recorded. The CIE L*a*b* color values for each specimen before and after aging were compared with each other and ΔE values were calculated based on the data obtained.

Statistical analysis

All statistical analyses and calculations were completed using the SPSS 15.0 (Chicago, IL) statistical program. Differences in L*, a*, b* and ΔE values of all-ceramic discs based on brand, core thickness or aging were analyzed. The Kolmogorov-Smirnov test was used to evaluate the distribution of the data. The Kruskal-Wallis multiple comparison test was used to analyze the effects of aging on the color differences of all-ceramic systems. The Wilcoxon signed rank test was used to evaluate the effects of core thickness within the groups. To compare color differences between two groups, the Bonferroni correction Mann Whitney U-test was performed. Statistical significance was determined given a p-value less than 0.05.

Results

L, a*, b* parameters*

Table II shows means and standard deviations for the CIE L*a*b* values of the IC, EM and K groups before and after aging. The effect of aging on the L*, a* and b* values was statistically significant regardless of core thicknesses ($p < 0.001$). CIE a* values increased with increasing core thickness for all IC, EM and K groups. However, such increases in core thickness were correlated with decreasing CIE L* and b* values. After the aging process, the EM and K specimens had decreased L* and b* values and, therefore, were darker, more opaque and more blue. They also had increased a* values, which resulted in specimens with more red. Conversely, among the IC specimens, there was an increase in the a* values and a decrease in the b* values; the most color change was observed among the IC specimens.

ΔE parameters

Statistically significant differences were observed between the ΔE values of the IC, EM and K groups using the Kruskal-Wallis multiple comparison test. The aging process significantly affected the color difference (ΔE) of all ceramic systems ($p < 0.001$), regardless of specimen core thickness. When the ΔE values of the all-ceramic groups were compared, the IC group

Table II. Material specification, mean color parameter (L*, a*, b*) values along with SDs of ceramic groups as determined by spectrophotometer ($n = 10$ for each group).

		Mean (SD)						
Material	Core thickness (mm)	L^*_1	a^*_1	b^*_1	L^*_2	a^*_2	b^*_2	Significance*
IC	0.5	79.4 (0.51)	1.89 (0.10)	14.9 (0.42)	78.5 (0.54)	1.74 (0.18)	17.0 (0.40)	a
	0.8	80.1 (0.09)	1.88 (0.05)	14.2 (0.17)	79.0 (0.16)	1.83 (0.08)	16.4 (0.48)	a
	1.0	79.7 (0.28)	1.90 (0.04)	13.8 (0.25)	78.7 (0.35)	1.83 (0.05)	16.2 (0.39)	a
EM	0.5	73.5 (1.41)	1.79 (0.15)	18.9 (0.68)	71.9 (1.33)	2.54 (0.36)	18.1 (0.82)	b
	0.8	72.1 (0.78)	1.62 (0.14)	18.1 (0.53)	72.0 (0.78)	2.33 (0.25)	17.2 (0.75)	b
	1.0	72.7 (0.86)	1.36 (0.31)	17.5 (0.52)	71.8 (0.90)	1.87 (0.22)	16.7 (0.60)	b
K	0.5	75.5 (0.29)	2.88 (0.14)	16.8 (0.01)	74.4 (0.23)	3.09 (0.10)	17.3 (0.40)	c
	0.8	72.8 (0.32)	2.61 (0.16)	15.6 (0.30)	71.9 (0.33)	2.73 (0.07)	16.4 (0.44)	c
	1.0	71.6 (0.28)	2.38 (0.05)	15.4 (0.16)	70.8 (0.20)	2.47 (0.05)	16.4 (0.16)	c

*Within any column means with the same letters are not significantly different ($p > 0.05$). Different letters indicate significantly difference of groups ($p < 0.\ 001$).

L^*_1, a^*_1, b^*_1: Color parameters before aging; L^*_2, a^*_2, b^*_2: Color parameters after aging.

had the highest mean color difference ($\Delta E = 2.46$) and the K group had the lowest ($\Delta E = 1.19$).

The mean ΔE values and standard deviations for the different core thicknesses of each all-ceramic system are summarized in Table III. The effect of core thickness on color change was statistically significant between the different all-ceramic groups. ΔE values were not significantly different for different core thicknesses within each group (Table III). The interactions between the ΔE values of the IC, EM and K groups are presented in Table IV. The following core thicknesses had the highest ΔE values: 0.5 mm-thick specimens in the IC groups ($\Delta E = 2.52$), 1.0 mm-thick specimens in the K groups ($\Delta E = 1.29$) and 0.5 mm-thick specimens in the EM groups ($\Delta E = 1.86$) (Figure 3). The Bonferroni correction Mann Whitney U-test revealed a significant difference between the ΔE values of K and IC groups of the same core thickness ($p < 0.001$) (Table V).

Discussion

The present study showed the changes in the color parameters of the all-ceramic systems ($L^\star$, $a^\star$, $b^\star$, ΔE) were correlated with core thickness and artificial aging. The IC group had higher color change values after aging than the other all-ceramic groups. The K and EM groups had similar change values. Because of the porcelain sub-structure of all-ceramic systems, restorations can achieve esthetic results much closer to the natural tooth due to reflected light and the depth of translucency [24]. In the current study; IC, EM and K specimens were prepared at different core thicknesses and subjected to aging as they are frequently used in clinical appliances due to their esthetic features [25].

The esthetics of all-ceramic materials change depending on the properties of the material, manipulative variables and the environment [7]. Stevenson and Ibbetson [19] reported that the shades of all-ceramic restorations were also influenced by tooth color, thickness of the ceramic layers and material opacity. However, lithium disilicate cores should be fabricated at a minimum thickness of 0.8 mm and glass infiltrated and yttrium stabilized zirconia cores at 0.5 mm according to the manufacturers' recommendations [15]. Heffernan et al. [15] and Heydecke et al. [3] reported that changes in core thickness, veneer thickness or both can cause significant differences in the optical properties of all-ceramics. In the present study, specimen core thicknesses were determined to be in the range of 0.5–1.0 mm and all the veneer thicknesses were 1.0 mm. These variations in thickness would have influenced the color of the specimens, although a standard white background was used to minimize the influence of background on the measured color.

Table III. Color differences (ΔE) values of the ceramic groups after aging ($n = 10$ for each group).

Material	Core thickness (mm)	Mean (SD) ΔE	Significance*
IC	0.5	2.52 (0.16)	a
	0.8	2.38 (0.40)	a
	1.0	2.49 (0.21)	a
EM	0.5	1.86 (0.85)	b
	0.8	1.81 (0.65)	b
	1.0	1.34 (0.36)	b
K	0.5	1.23 (0.36)	c
	0.8	1.06 (0.26)	c
	1.0	1.29 (0.12)	c

*Within any column means with the same letters are not significantly different ($p > 0.05$). Different letters indicate significantly difference of groups ($p < 0.001$).

Table IV. p-values of Bonferroni correction and Mann Whitney U on the interaction between the all-ceramic materials' mean ΔE values regardless of the core thicknesses.

Source ΔE	p
EM × K	0.003
K × IC	< 0.001
EM × IC	< 0.001

Using the Lava and IPS e.max Press all-ceramic systems, Son et al. [2] demonstrated that CIE $L^\star$ values decreased as the veneer porcelain thickness increased between 0–2.0 mm. On the other hand, the previous study reported that CIE $L^\star$ values increased as the veneer thickness increased [6]. They also noted that small changes in the thickness and shade of the porcelain layers can influence the final shade of the layered porcelain specimen. In the present study, although the CIE $L^\star$ and $b^\star$ values generally decreased, the $a^\star$ values increased as the core thickness increased in the EM and K groups. The specimens appeared more blue/red because of increasing $a^\star$ and decreasing $b^\star$ values. However, in the IC group, $a^\star$ values decreased.

Dental restorative materials must withstand widely varied conditions in the mouth, including temperature changes, continuous exposure to moisture and mechanical use of the restoration. Light exposure and humidity changes can be simulated in a so-called 'artificial aging' which has been widely used for the testing of dental resin and ceramic materials [3,20,23,26–28]. The manufacturer of the universal test machine used in this study claimed that 300 h of artificial aging is equivalent to 1 year of clinic service. In the current study, all-ceramic systems were artificially aged for 200 h to evaluate color changes. ΔE units were calculated from color values measured before and after aging. Although significant changes in color were observed after aging for all systems, the

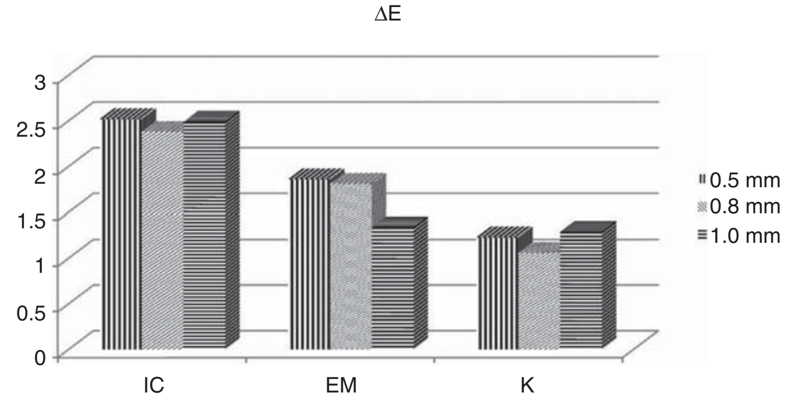

Figure 3. The mean ΔE values of ceramic specimens against three types of core thickness.

IC groups had slightly higher color change values (ΔE) compared to the EM and K groups. The K groups had the lowest values. The IC and EM 0.5 mm core groups had the highest ΔE values when compared to the K groups (Table III). The relationship between core thickness and color difference after aging was not statistically significant for the all-ceramic core groups.

Several *in vitro* studies have reported that color changes in porcelain materials can occur due to their metal oxide content [27,29]. Metal oxides are added to the porcelain to obtain acquired color shades. The metal oxides can easily break down under ultraviolet radiation, causing peroxide formation and changing the color of the porcelain. According to this theory, in the present study, color changes in all-ceramic systems may have been due to ultraviolet light exposure during the aging process.

Generally, it's impossible for the human eye to differentiate minimal numerical color differences in dental materials. According to previous studies on porcelain color change, ΔE values lower than 1 are not clinically detectable by the human eye [21,30]. Paul et al. [31] demonstrated that spectrophotometric color evaluation shows rather significant results compared to visual shade matching. Therefore, in the present study, spectrophotometers and CIE were used to objectively measure the current numerical color results, yielding data which could be evaluated statistically.

Table V. *p*-values of comparison in same core thicknesses between the mean ΔE values of all-ceramic materials.

Material/Core thickness ΔE	*p*
EM/0.5 × K/0.5	0.342
K/0.5 × IC/0.5	< 0.001
EM/0.5 × IC/0.5	0.414
EM/0.8 × K/0.8	0.126
EM/0.8 × IC/0.8	0.882
K/0.8 × IC/0.8	< 0.001
EM/1.0 × K/1.0	0.562
EM/1.0 × IC/1.0	0.005
K/1.0 × IC/1.0	< 0.001

Light transmission or translucency is one of the important optical properties of all-ceramic systems and is affected by background color. Although all-ceramic systems are sometimes suggested for endodontically treated and/or discolored teeth in clinical practice, it is clear that the masking ability of the core material affects final esthetic results [1,32,33]. IPS e.max cores, which contain lithium disilicate crystals, are superior to alumina or zirconia cores for producing the desired esthetic appearance because of their translucency [19,34]. For this reason, IPS e.max cores are affected by the background color and show color differences more than other all-ceramics. In the current study, a standard white tile was used as the background to minimize the background's influence on the measured color, the variations in core thickness would have affected the color differences of the current all-ceramic systems.

In this *in-vitro* study; disc-shaped specimens of three different core thicknesses were fabricated out of all-ceramic materials and evaluated using an artificial aging process to simulate oral environmental conditions. It is important to emphasize that the aging process used in this study is only a first step toward predicting clinical performance. Further *in vivo* studies should be performed on the clinical evaluation of core thickness and color differences for better characterization of all-ceramics.

Within the limitations of the present study, the changes in color and L*, a*, b* and ΔE values of all-ceramic systems were affected by core thickness and aging. ΔE values were less influenced by core thickness alone. The IC and EM 0.5 mm core groups had the highest ΔE values when compared to the K groups. The IC groups had higher mean color difference values than the other all-ceramic groups and the K groups had lower ΔE values. The optical properties of available core materials enable the clinician to make appropriate choices when faced with various esthetic challenges.

Acknowledgments

This study (project number AR-2010/28) was supported by Gulhane Military Medical Academy Scientific Research Commission, Ankara, Turkey. The authors would like to thank the manufacturers for supplying the materials tested.

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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